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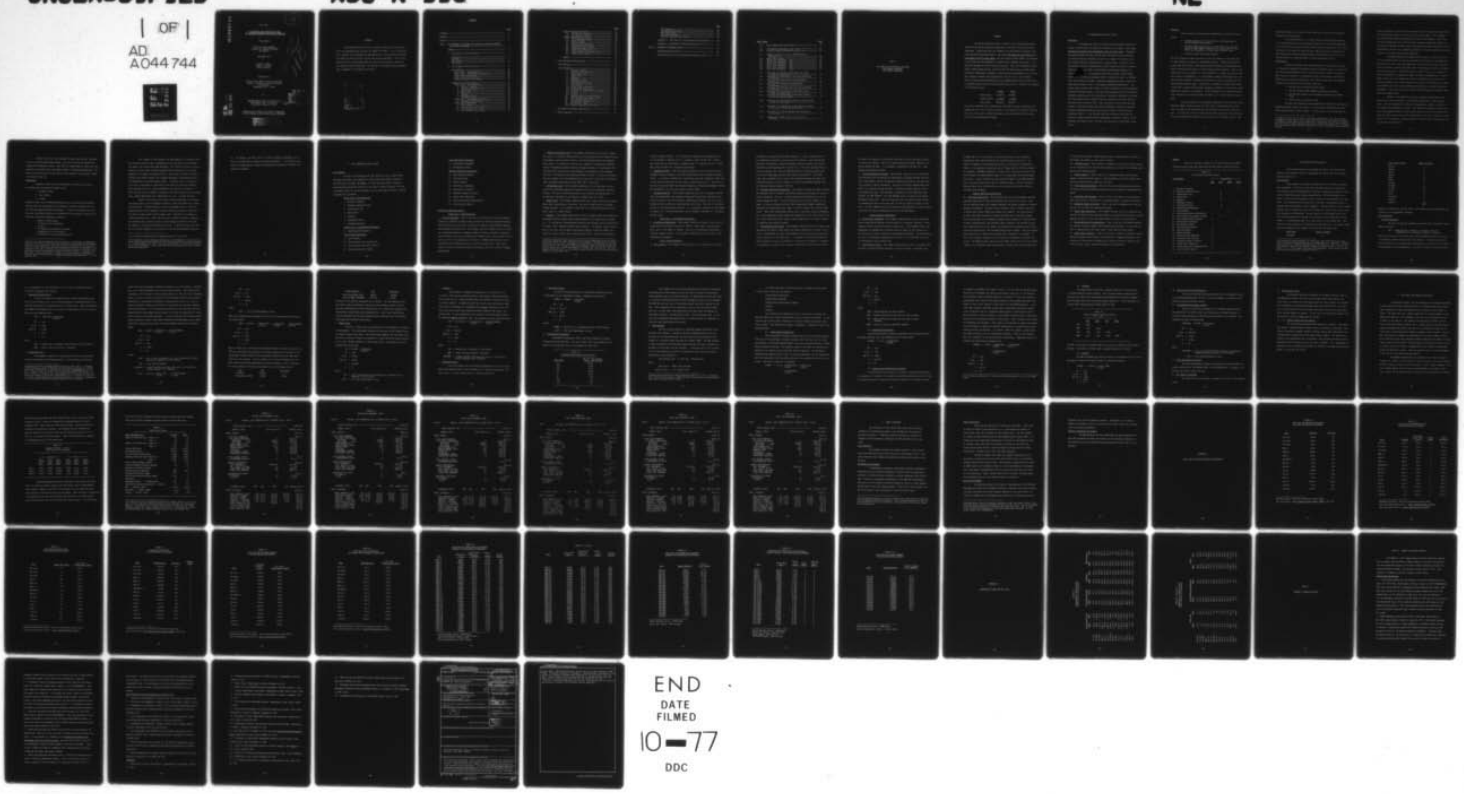

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AN OPERATING AND SUPPORT COST MODEL FOR AIRCRAFT CARRIERS AND SURFACE COMBATANTS

Final Report

OFFICE OF NAVAL RESEARCH
Contract No. N00014-73-C-0083
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FOREWORD

This document serves as both a technical report and a final report of work accomplished under Contract No. N00014-73-C-0083. It is in two parts. Part I details the development and implementation of an operating and support cost model for Naval aircraft carriers and surface combatants. Part II summarizes all work accomplished under the contract and provides a listing of all technical reports submitted. The contract's performance period extended from 1 September 1972 through 31 July 1977.

CONTENTS

TABLES

PART I

AN OPERATING AND SUPPORT COST MODEL FOR AIRCRAFT CARRIERS AND SURFACE COMBATANTS

SUMMARY

The study described in Part I resulted in an operating and support (O&S) cost-estimating capability applicable to aircraft carriers and surface combatants. Twenty-three O&S cost elements were identified and defined, with close adherence being maintained to the draft CAIG Operating and Support Cost Development Guide for Naval Ships, the Navy Resource Model (NARM), and the work of the Visibility and Management of Support Costs (VAMOSC) Study Group. Cost data were obtained from three principal sources: Navy Cost Information System (NCIS), NARM Program Factors, and the Center for Naval Analyses' SOCER Study. Procedures consisting of parametric cost-estimating relationships, cost factors and "thruput" estimates were developed for the full set of cost elements. Those procedures were incorporated into an automated model which was then used to estimate annual O&S costs for the DD-963 and the FFG-7. Results (in thousands of FY76 dollars) were:

	DD-963	FFG-7
Direct Costs	$ 8,097.5	$6,888.4
Indirect Costs	2,403.0	1,738.9
Total Costs	$10,500.5	$8,627.3

The report concludes with a discussion of the model's present limitations and suggestions as to how it might be refined. The potential for greatest improvement lies in the area of Depot Maintenance costs, specifically Ship Overhaul and the Fleet Modernization Program.

1. INTRODUCTION AND STUDY DESIGN

Background

On December 29, 1975, the Office of the Assistant Secretary of Defense (Installations and Logistics) circulated for comment a draft CAIG Operating and Support Cost Development Guide for Naval Ships. Subsequent discussion between OASD(I&L) and the Navy, specifically the CNO Advisor for Resource Analysis (Op-96D), resulted in a number of revisions to the draft which have been incorporated in a revised Guide. As a part of the discussions, OASD(I&L) requested that Op-96D initiate an effort to develop operating and support (O&S) cost-estimating relationships (CER's) for selected naval ships. In compliance with OASD's request, Op-96D tasked Administrative Sciences Corporation (ASC) to perform the work. On October 7, 1976, ASC delivered to Op-96D a technical memorandum entitled, "Naval Ship Operating and Support Costs: A Preliminary Estimating Capability." The present report details ASC's effort to refine and update the cost-estimating procedures reported therein. There were some changes made in the parametric estimating equations and in the selection of predictor variables, but mainly the work described herein differs from the previous in the fact that FY76 data were used in place of FY75. Also, the focus of this effort has been limited to aircraft carriers and surface combatants, whereas the original technical memorandum presented some results relating to nuclear attack submarines (SSN's.) It was learned from that experience that there are technical problems associated with generalized, parametric analysis of SSN operating and support costs, and that the results are of relatively little utility.

Approach

Three principal objectives were established at the outset of the study:

1. Emphasize generality of application in the development of cost-estimating relationships.

2. Maintain compatibility with the draft CAIG Guide, the Navy Resource Model (NARM) Program Factors Manual, and the Visibility and Management of Support Costs (VAMOSC) Study.

3. Utilize previous work where possible.

The first objective stems from the fact that the products of this work will be used primarily in support of CAIG/DSARC analyses. Those analyses almost always take place before a ship begins normal operations, and sometimes even before construction has begun or final design has been approved. Thus, to the extent that the cost analysis is to be "parametric," it must focus on only the most general of parameters, i.e., displacement tonnage, shaft horsepower, crew size, and the presence or absence of certain major types of weaponry and communications/electronics gear. Although it is possible to develop CER's which contain more refined and intuitively appealing variables - total electric power generating capability, for example - those variables are not suitable because their values are not typically known at DSARC I, II, or even later in the program.

The second objective, maintaining compatibility with the CAIG Guide, NARM and VAMOSC, arises from the fact that each of these either has or will have a bearing on the identification and estimation of O&S costs within the Navy. It turned out that this objective was fairly easily met since there are only minor differences between the structures of cost elements in each. What

differences exist are in level of detail and tend to reflect the functional orientation of each system.[1]

The third objective, to utilize previous analysis where possible, is a rather obvious one, but was important because of the potential magnitude of the problem at hand and the rather limited resources allotted to this effort. Fortunately, the Center for Naval Analyses (CNA) had recently completed the Ship Overhaul Cost Estimating Relationships (SOCER) Study, which was of significant benefit in developing CER's for depot maintenance costs.

Data Sources

Because the VAMOSC Group was established for the specific purpose of designing a Management Information System for ship O&S costs, it was thought that the reports published by that study group would be helpful in locating data sources for use here. Unfortunately, many of the sources identified by VAMOSC are not presently operational. Thus other sources had to be obtained. In general, the data used in this study came from:

1. The Navy Cost Information System (NCIS).
2. The Navy Resource Model (NARM) Program Factors Manual.
3. The CNA Ship Overhaul Cost Estimating Relationships (SOCER) Study.
4. Other sources for specific items.

The Navy Cost Information System/Operations Subsystem of the Resource Management System presents the status of the Operations and Maintenance, Navy (OMN) appropriation by major claimant. In many cases, costs are described in

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[1]It might be noted that in order to maintain compatibility, two cost elements - Exchanges (#13) and Issues (#14) - were revised after the study began to reflect a comparable change made in the VAMOSC Study. The change was made by the VAMOSC Group in order to comply with DOD Instruction 7220.29, 20 October 1975, "Guidance for Cost Accounting and Production Reporting for Depot Maintenance and Maintenance Support."

detail according to function, and are charged to the Unit Identifier Code (UIC) of the benefiting activity (in this case a particular ship). As an example, the NCIS contains annual conventional fuel costs by hull number. Since this is actual expenditure data, there are wide variations within ship classes reflecting the different activity rates of the ships and other extraneous factors. Nevertheless, the NCIS was considered preferable to other available data sources because it does report actual ship experience.

The NARM Program Factors Manual was utilized as a data source only for cost elements where no data was available from the NCIS or the SOCER Study. The reason for this is that the NARM is not a data collection system like the NCIS, but rather an empirically-based model for examining the costs of alternative force structures. Although it deals in "micro" units, i.e., ships, aircraft and personnel by numbers and types, the NARM is fundamentally a "macro" model in that its cost-estimating factors are developed in such a way as to assure consistency with various budget control totals. Nevertheless, for some cost elements such as the Fleet Modernization Program, it was the only source available. It was also used as the primary source pertaining to Indirect Operations and Support Costs.

Results of the SOCER Study, which represented approximately ten man-years of effort, provided a rich data base applicable to ship overhaul costs. With the exception of crew pay and allowances, overhaul accounts for the largest O&S expenditure for ships. The SOCER cost-estimating relationships were not altogether useful for the present purposes, since they included variables for which values are typically unavailable in the early stages of a ship's life-cycle. Consequently, further analysis of that data was conducted here and is described in Section III.

Finally, there are a few elements for which data were not contained in any of the previously named sources. Two such cases are APA Material Exchanges and APA Material Issues. Some data for these elements, albeit not very detailed, is available from Procurement Annexes to DOD Budget Submissions. The extent to which this data can be used for cost estimation is discussed further in Sections II and III.

Methodology

Generally, there will be three methods utilized in this report to estimate ship operating and support costs:

1. Parametric CER's
2. Cost Factors
3. Thruput

Parametric CER's will be developed through the use of statistical regression analysis where the supporting data is adequate, and where the nature of the cost element suggests parametric estimation. In each such instance, the full data base (including definition of variables) will be provided, along with the following conventional regression statistics:

- Number of observations
- t-ratios of the coefficients
- F value
- $\bar{R}^2$ (adjusted for degrees of freedom)
- Standard error of the estimate
- Determinant of the correlation matrix[2]

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[2]This is a bit less conventional than the others. It provides a standardized measure of the overall intercorrelation (multicollinearity) between independent variables in the regression. When the value of the determinant is less than about .10, there may be serious multicollinearity problems. As something of an historical note, one of the early but still important pieces of diagnostic literature on the multicollinearity problem arose from studies of destroyer overhaul costs. See D. Farrar and R. Glauber, "Multicollinearity in Regression Analysis: The Problem Revisited," Review of Economics and Statistics, Vol. XLIX, February 1967.

For a number of cost elements, the development of a parametric CER was precluded either by data considerations or by the nature of the element. For these, cost factors have been developed. The factors can take the form of percents of other costs, standard planning factors accepted by the costing community, or averages of historical data. Cost factors are also utilized to estimate the indirect support cost elements employing, as mentioned earlier, the methodology of the Navy Resource Model. In general, each of these indirect costs is allocated to force units on the basis of some proxy variable which measures the unit's relative demand for the resource in question. In most cases the proxy is number of personnel, but other factors such as steaming hours, annual maintenance cost, annual O&M cost, etc., are also involved.[3]

Finally, some costs are "thruput," meaning developed on a case-by-case basis, when it is not inherently possible to deal with them in any generalized fashion.[4] The best example of this is Expendable Stores. This cost depends entirely on the weaponry carried by the ship and must be estimated on the basis of usage rates of each ordnance item. Personnel is an example of a modified thruput item. Since the crew size is usually available, computing the personnel cost is simply a matter of multiplying the number of officers and number of enlisted by prevailing cost rates. It should be noted also that any of the other elements can be thruput if a particular application requires

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[3]For a complete explanation, see "Program Factors," 27 July 1976.

[4]The discussion in this paragraph anticipates the development of a Ship O&S Cost Model which integrates the results of the study andprovides an automated capability for generating a full set of O&S cost estimates from a relatively small number of input parameters. Such a model has been developed and its use is demonstrated in Section IV.

it. For instance, any time there is a radical change in technology, one or more of the CER's may no longer be directly applicable. It is then the cost analyst's responsibility to make the appropriate revisions and "thruput" the resultant estimates.

2. COST ELEMENTS AND DATA SOURCES

Cost Elements

As part of the present study, ASC selected a set of twenty-three operating and support cost elements for Naval ships which adhere closely to the CAIG Guide, the NARM, and VAMOSC. In some cases the Navy's accounting system dictated variations from one or the other of these references, but from a conceptual point of view the attempt is to cost the same activities. The ASC categories are as follows:

Direct Unit - Ship Operations

1. Military Personnel
2. Temporary Additional Duty
3. Conventional Fuel
4. Repair Parts
5. Supplies
6. Expendable Stores
7. Purchased Services

Direct Unit - Intermediate Maintenance

8. Intermediate Maintenance

Direct Depot Maintenance

9. Ship Overhaul
10. Selected Restricted Availability
11. Non-scheduled Ship Repair (RA/TA)
12. Fleet Modernization Program

Direct Recurring Investment

13. APA Material Exchanges

14. APA Material Issues

Indirect Operations and Support

15. Base Operating Support

16. Training Support

17. Medical Support

18. Recruiting & Examining

19. Transients & Prisoners

20. Permanent Change of Station

21. Supply Depot Operations

22. Second Destination Transportation

23. Other Logistic Support

Definitions and Data Sources

Direct Unit - Ship Operations

1. Military Personnel - This is the cost of the services of all ship manpower computed at composite standard rates as defined in the Navy Comptroller Manual, which includes basic pay, basic allowance for quarters, miscellaneous expenses and incentive and special pay. This element does not include the cost of trainees, unassigned personnel, permanent change of station, prisoners or patients. The NCIS reports this cost by applying the standard rates for each rank for persons on board at the beginning of the month. The NARM estimates this cost by multiplying the authorized manning by the FYDP average rates. This latter method is usually preferable because CAIG guidance calls for costing of authorized manning.

2. Temporary Additional Duty - The element includes the cost of ship's personnel travel for training, administrative or other purposes such as Homeport Travel Entitlement, Special Aircraft Charter, Crew Rotation/Deployment and Temporary Shore Patrol. It consists of costs such as commercial transportation charges, rental of passenger carrying vehicles, mileage allowances, and subsistence for travelers which includes per diem allowances and incidental travel expenses. This cost is collected by and reported through the NCIS. As costs are incurred, they are charged to the Unit Identification Code (UIC) of the ship and reported under the Budget Classification Code (BCC) "EB" - Fleet TAD.

3. Conventional Fuel - This includes the OMN cost of all petroleum, oil and lubricants (including additives) consumed by the ship for operations and maintenance. The cost of Conventional Fuel is also reported through the NCIS. It is primarily identified by its Element of Expense code "S" - Fuel.[1]

4. Repair Parts - This element identifies the cost of Navy Stock Account repair parts used in maintenance of the ship. The cost of Repair Parts is reported through the NCIS. It is primarily identified by its Functional/Sub-functional (FSF) code "XJ" - Repair Parts.

5. Supplies - This element identifies the cost of supplies which are neither replenishment spares reported under expense element 13 nor repair parts included in 4. It includes all non-maintenance supplies and equipage used by the ship and the ship's crew. Examples include items relating to the health, safety and welfare of the crew, such as medical and dental supplies, radiation badges, fire protection suits, charts, maps, binoculars and clocks. The cost of supplies is

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[1]The term "primarily" will be used in several cost element definitions in association with either the BCC, Sub-function, or Element of Expense that is the most descriptive of the cost. For example, ship POL costs are identified in the NCIS under DA XX S. "DA" is BCC for Fuel and Utilities, "XX" the Sub-functional code for not applicable, and "S" the Element of Expense code for ship POL. In this example we would cite "S" as the primary source because it is the most descriptive identifier of ship POL costs.

reported through the NCIS. It is computed by summing the costsidentified by (1) the Element of Expense code "T" - Supplies, under the BCC "DB" - Medical and Dental and (2) the Element of Expense codes "T" - Supplies and "W" - Equipment, under the BCC "DC" - Supplies and Equipage.

6. Expendable Stores - This cost element identifies the costs associated with expendable stores consumed by the ship and purchased from procurement appropriations. It consists of ammunition, pyrotechnics and other expendable items used in non-tactical operations such as targets, evasion devices, etc. This data is reported through the CAIMS (Conventional Ammunition Integrated Management System) and maintained by the Ship Parts Control Center (SPCC).

7. Purchased Services - This element identifies the cost of purchased services other than maintenance and includes printing and reproduction, ADP rental and contract services, rent and utilities, communication charges, and other miscellaneous services provided by other than Navy activities. The cost of Purchased Services is reported through the NCIS. It is primarily identified by the Element of Expense "M" - Utilities and Rents, and the Element of Expense "Q" - Purchased Services Other.

Direct Unit - Intermediate Maintenance

8. Intermediate Maintenance - This element consists of material, parts, and related services provided to the ship by tenders, repair ships, and equivalent shore units in the repair of vessels. The cost of intermediate maintenance is reported through the NCIS. It is primarily identified by the BCC "E2" - Ship Intermediate Maintenance.

Direct Depot Maintenance

9. Ship Overhaul - This element identifies the cost of regular ship overhauls

performed by both public and private shipyards. It also includes costs of post-shakedown availability, post-delivery availability, post-construction/ conversion availability, interim drydocking, interim overhaul, activation/ deactivation, and installation of nuclear core. The best available data for this cost element come from the SOCER Study which contains extensive data on all ships undergoing overhaul from FY1962 through FY1972. The SOCER Study, which provides data on repair and alteration man-days and repair and alteration material cost per overhaul, is taken from NAVSHIPS "Regular Overhaul Departure Report Summary," FY61-72.

10. Selected Restricted Availability - This element includes the labor, material and overhead costs of selected restricted availabilities performed at public or private shipyards. The cost of Selected Restricted Availability is not reported through the NCIS. The best available source for this element is the NARM. Its data is obtained from the "Navy Congressional Budget Submission, Operations and Maintenance, Navy (OMN)," by Fleet, Exhibit Op-19 (RA/TA & SRA costs). SRA's have traditionally applied only to aircraft carriers undergoing pre or post-deployment repair beyond the capabilities of the ship's crew or tender. Recent OPNAV decisions, however, have extended SRA's to certain classes of submarines and nuclear cruisers.

11. Non-scheduled Ship Repair - This element identifies the cost of depot level maintenance performed at both public and private shipyards as a result of casualty, voyage damage, and other unforeseeable occurrences which are beyond the repair capability of the ship's force. It consists of restricted avilability, which requires the ship to be present at the facility and renders it incapable of performing its mission; and technical availability, which does not require

The ship to be present at the facility and does not affect the ship's ability to perform its mission. The cost of Non-scheduled Ship Repair (RA/TA) is reported through the NCIS. It is primarily identified by the BCC "F2" - Non-scheduled Ship Repair (RA/TA).

12. Fleet Modernization Program - This element covers the cost of procuring and installing ship alterations and improvements including military and technical improvements, nuclear alterations, ordnance alterations, and other support provided at public facilities. The cost of the Fleet Modernization Program is not reported through the NCIS. Therefore the NARM estimate of this cost element was used. This estimate is identified in the NARM under "FMP PROCURE" and "FMP INSTALL." The "FMP PROCURE" factor is based on the NAVSEA OPN Budget Backup cost. After surveying the data, the Op-901 analyst selects a representative ship of the class that is used as a gauge for ships of that type. The "FMP INSTALL" factor is derived by using installation costs received from Op-43 and then re-adjusting the costs in the same manner.

Direct Recurring Investment

13. APA Material Exchanges - This element identifies the costs of repairing and/or replacing APA material items returned in an unusable condition. Unfortunately no data source was found for these costs. If the VAMOSC Study recommendations are implemented, provisions should be made for the collection of data which can be used to develop an estimating relationship. For the present, the cost of APA Material Exchanges will be assumed to be the same as the cost of APA Material Issues (element #14).

14. APA Material Issues - This element identifies the costs of purchasing APA material to replace material surveyed or lost by the ship. The elment also

includes the cost of the nuclear core provided during a recore operation. Installation labor and NSA material are included under elements 9-12. Although no completely satisfactory data source is available for APA Material Issues, it was possible to make some use of "Backup Data for FY1978 in Support of Estimates - NAVCOMPT Submission," 2 August 1976. This source contains the FY76 estimates for Replenishment Spares of the appropriate OPN and WPN Budget Activities. A proxy variable was then selected (similar to the NARM methodology) to distribute those costs back to individual ships. The cost estimates developed here do not include the cost of the nuclear core itself, which is available from the NARM.

Indirect Operations and Support

15. Base Operating Support - This includes the cost of base manpower and base operating funds used to operate and maintain base services for ships. This and the remaining eight cost elements represent the general category of Indirect Operations and Support. Because of their indirect nature, no data sources are available which report these costs against hull numbers. Any quantification of these costs must necessarily result from some type of allocation scheme. With the exception of cost elements 21(Supply Depot Operations), 22(Second Destination Transportation), and 23(Other Logistic Support), the indirect support cost elements as well as the scheme for estimating their magnitude used in this study are taken directly from the NARM Program Factors Manual. The cost elements mentioned above are computed and reported under "Logistics" in the NARM. In this study, however, elements 21-23 are broken out separately for better visability. The NARM procedure takes the total budget authorization for the program elements in the Indirect Operations and Support category and allocates them back

to the individual weapon systems based on proxy variables which are chosen to approximate the demand for each type of support.

16. Training Support - This element is comprised of the cost of paying personnel in training who will replace ship personnel, the cost of the training staff, and training operating funds.

17. Medical Support - This is the cost of medical personnel and materials needed to provide medical support to ship personnel and the base support personnel who provide direct support to the ship.

18. Recruiting and Examining - This is the cost of staffing and maintaining recruiting offices and examining stations to provide adequate replacement personnel.

19. Transients and Prisoners - This is the pro rata share of non-productive labor which exists in the Navy due to personnel being in transit or detention.

20. Permanent Change of Station - This is the cost of permanent duty station rotation for all ship and supporting personnel.

21. Supply Depot Operations - This element contains the cost of material and salaries of depot and base personnel needed to perform the distribution of ship supplies and parts to and from supply depots to points of use and repair.

22. Second Destination Transportation - This is the cost of shipping supplies and material needed to support ship equipment and personnel. It includes the cost of shipping spare and repair parts to and from the repair depots.

23. Other Logistic Support - This is the cost of a number of programs, usually centrally managed, which support ship operations. Examples belonging in this category are publications, engineering and technical services, explosive ordnance disposal, special weapons maintenance and calibration.

Summary

Table 2-1 provides a summary of the twenty-three cost elements included in this study, and identifies the data source selected for each.

TABLE 2-1

Cost Elements and Data Sources

Cost Element	Data Source			
	NARM	NCIS	SOCER	OTHER
1. Military Personnel				X
2. Temporary Additional Duty		X		
3. Conventional Fuel		X		
4. Repair Parts		X		
5. Supplies		X		
6. Expendable Stores				X
7. *Purchased Services*		X		
8. Intermediate Maintenance		X		
9. Ship Overhaul			X	
10. Selected Restricted Availability	X			
11. Non-scheduled Ship Repair (RA/TA)		X		
12. Fleet Modernization Program	X			
13. APA Material Exchanges				X
14. APA Material Issues				X
15. Base Operating Support	X			
16. Training Support	X			
17. Medical Support	X			
18. Recruiting and Examining	X			
19. Transients and Prisoners	X			
20. Permanent Change of Station	X			
21. Supply Depot Operations	X			
22. Second Destination Transportation	X			
23. Other Logistic Support	X			

3. COST-ESTIMATING RELATIONSHIPS

This section details the development of CER's, cost factors and thruputs which provide a basis for estimating the twenty-three cost elements defined in Section II.

Data Handling

Three methods of grouping the sample data for statistical analysis were considered. First was to treat each individual ship as an observation. This procedure has the disadvantage of implicitly weighting the sample in favor of ship classes having the largest representation. The second method was to select a "typical" ship from each class to be used as the observation for that class. The problems with this were that it excluded a considerable amount of relevant data and entailed too much judgement. The third method, the one finally selected, was to average the costs for all ships in a given class, and to treat each average as an observation. Further support for this method lies in the fact that the objective of the CER is to produce a cost estimate which corresponds to a representative ship in a class, and not to any single ship. Thus the use of class averages is consistent with that objective.[1] The classes which made up the sample and the number of ships in each are shown below:

Ship Class	Number in Sample
DD FRAM I	17

[1]This procedure raises something of a technical point which should be noted. The use of class averages eliminates all between-ship cost variation. Although that variation is considered extraneous for the purpose of this study, its removal tends to make the conventional regression statistics ($\bar{R}^2$, t, and F) "look better;" i.e., to be higher, than they would otherwise. This should be remembered when interpreting the regression results.

Ship Class (cont'd.)	Number in Sample
DD-931	9
DD-945	5
DDG-37	9
DDG-35	2
DDG-2	23
FFG-1	6
FF-1037	2
FF-1040	10
FF-1052	46
CG-16	9
CG-26	9
CVA-64/63	2
CGN-36	2
CVAN-65	1
	152

Appendix A contains all the data used in the analyses and also identifies the sources for the independent variables.

Cost Estimation

1. Military Personnel

The cost for military personnel associated with a ship may be estimated as follows:

MPN = NARM MPN Factor (Officers) x Number of Officers
+ NARM MPN Factor (Enlisted) x Number of Enlisted

Since the crew size is one of the early design parameters, there is little or no estimation problem associated with this element. It should be noted the model performs only a straightforward computation using crew size as a "given." An assessment of the reasonableness of the crew size input value was excluded

as a consideration in this study since it is not part of Op-96D's charter as the Navy's independent cost analyst.

2. Temporary Additional Duty

The cost of TAD can be assumed to bear a stable relationship with the size of the ship's crew. The following parametric estimating equation was therefore developed with regression results as shown below. (Here and hereafter, the numbers in parentheses are t-ratios and are significant at the .05 level or better unless otherwise noted.)

$$\begin{aligned} TAD &= -1845.264 + 36.205\ CREW \\ &\qquad\qquad\qquad\quad (23.784) \\ \bar{R}^2 &= .977 \\ S.E.E. &= 5315 \\ DET\ X'X &= 1.000 \\ F &= 565 \\ N &= 15 \end{aligned}$$

where,

TAD = annual cost of temporary additional duty in FY76 dollars

CREW = ship's crew size (officer + enlisted)

3. Conventional Fuel

The parametric equation for conventional fuel cost was developed through the application of Ridge Regression.[2] This technique was employed

[2]The seminal articles on Ridge Regression are A.E. Hoerl and R. W. Kennard, "Ridge Regression: Biased Estimation for Nonorthogonal Problems" and "Ridge Regression: Applications to Nonorthogonal Problems," Technometrics, Vol. 12, No. 1, February 1970, pp. 55-82. For further discussion in the context of Naval systems cost analysis, see "Ridge Regression with Non-Zero Priors: Some Monte Carlo Results," ASC R-105, Annual Report: Vol. II, August 31, 1973 and H.L. Eskew, "Ridge Regression and Bayesian Inference In Costing," presented at the 31st Military Operations Research Symposium, 19-21 June 1973.

because the three independent variables considered to be cost drivers - displacement, total shaft horsepower, and a nuclear dummy variable - were highly intercorrelated. One "solution" to this problem would be to omit one of the variables. However, this is not really a solution for both technical and practical reasons. Technically, it introduces the problem of "specification bias;" i.e., the included variable(s) picking up the effects of the omitted one and thus producing misleading statistics. It is a practical problem since the resultant cost-estimating equation (and perhaps others related to it) would be insensitive to alternative values of the omitted parameter. As can be seen from the following least-squares regression results, both shaft horsepower and displacement bear a highly significant relationship with fuel costs when examined alone with the nuclear dummy:

$$\begin{aligned} \text{FUEL} &= 166.021 + \underset{(4.476)}{.001974}\text{SHP} - \underset{(-4.910)}{490.220}\ \text{NUCDUMMY} \\ \bar{R}^2 &= .674 \\ \text{S.E.E.} &= 118 \\ \text{DET X'X} &= .815 \\ F &= 15.487 \\ N &= 15 \end{aligned}$$

where,

FUEL = cost of fuel, lubricants, etc., per steaming hour (underway and not underway) in FY76 dollars

SHP = total shaft horsepower

NUCDUMMY = a dummy variable that takes the value 1 if the ship is nuclear powered, and 0 otherwise

$$\text{FUEL} = 262.212 + \underset{(3.838)}{.005424}\ \text{DISP} - \underset{(-4.551)}{511.620}\ \text{NUCDUMMY}$$

$\bar{R}^2$ = .614

S.E.E. = 129

DET X'X = .760

F = 12.159

N = 15

where,

DISP = full load displacement in tons

When the relationship was estimated with each of the three predictors present, the results were:

FUEL = 130.043 − .002351 DISP + .002756 SHP − .00047 NUCDUMMY
(-0.439) (1.498) (-4.309)

$\bar{R}^2$ = .725

S.E.E. = 122

DET X'X = .038

F = 9.694

N = 15

This is clearly not a satisfactory estimating equation; although the overall fit ($\bar{R}^2$) and significance (F) measures are certainly adequate, the estimate of the displacement variable (DISP) has an implausible negative sign and large sampling error (low t-value). This was judged to be a direct consequence of the high correlation between displacement and shaft horsepower (.973). Therefore, the ridge estimation procedure was employed with the following results:

Coef.	Est.	Std. Error
Intercept	212.082	—
Displacement (DISP)	.001462	.00079

Coef. (cont'd.)	Est.	Std. Error
Shaft Horsepower (SHP)	.00105	.000288
Nuclear Dummy (NUCDUMMY)	-381.700	82.250

The above is an entirely reasonable set of results. All the variables carry the correct sign and although t-values for ridge estimates cannot be given the same interpretation as with least-squares, it is noted that estimates are substantially larger than their standard errors. Also, those coefficients are more plausible than the ones obtained earlier when only two of the three right-hand-side variables were present.

4. Repair Parts

The cost of repair parts per steaming hour is estimated as a function of displacement. The displacement variable was also used in the original study to estimate repair parts costs. This consistency suggests that while that variable may be acting as a proxy for complexity or other sub-system characteristics, it is a very reliable predictor of repair parts costs. The results, on a per steaming hour basis, were:

$$RP = 28.083 + \underset{(10.299)}{.00263}\ DISP$$

$$\bar{R}^2 = .882$$

$$S.E.E. = 27.089$$

$$DET\ X'X = 1.000$$

$$F = 106.080$$

$$N = 15$$

where,

RP = cost of repair parts per steaming hour (underway and not underway) in FY76 dollars

DISP = full load displacement in tons

5. Supplies

This element is estimated parametrically as a function of (1) crew size, since the costs involved relate to the health, safety and welfare of the crew; and (2) a dummy variable that takes account of whether the ship is nuclear powered. It should be noted that in this case the positive algebraic sign of the dummy is in agreement with a priori expectation that a nuclear ship would require more health and safety supplies than would a non-nuclear ship. In the conventional fuel equation, the nuclear dummy carried the expected negative algebraic sign. The regression results are shown below:

$$SPL = 44{,}797.515 + \underset{(3.016)}{248.260}\ CREW + \underset{(2.194)}{478{,}830}\ NUCDUMMY$$

$$\bar{R}^2 = .637$$

$$S.E.E. = 251{,}304$$

$$DET\ X'X = .764$$

$$F = 13.29$$

$$N = 15$$

where,

SPL = annual cost of supplies in FY76 dollars

CREW = ships crew size (officer + enlisted)

NUCDUMMY = a dummy variable that takes the value 1 if the ship is nuclear powered, and 0 otherwise

6. Expendable Stores

This cost element was not estimated parametrically or by any other generalized method because of the variability of ordnance requirements from ship to ship. It must be dealt with on a case-by-case basis.

7. Purchased Services

The cost of Purchased Services is estimated parametrically with displacement as the independent variable. Regression results were:

$$\text{PURSER} = 48{,}480 + \underset{(7.985)}{8.845}\ \text{DISP}$$

$$\bar{R}^2 = .817$$

$$\text{S.E.E.} = 117{,}372$$

$$\text{DET X'X} = 1.000$$

$$F = 63.76$$

$$N = 15$$

where,

PURSER = annual cost of purchased services in FY76 dollars

DISP = full load displacement in tons

8. Intermediate Maintenance

Intermediate Maintenance (IMA) costs were estimated by factors developed from the NCIS data. The cost factors, which are averages of the ships in the respective class, are presented in Table III-1.

Table 3-1

Intermediate Maintenance Cost Factors

Ship Class	IMA Cost Per Steaming Hour - FY76 Dollars
FF	$12.30
FFG	13.80
DDG	21.40
DD	20.20
CG	10.10
CV	1.00
CGN	1.90
CVAN	3.20

This element was not estimated parametrically because no meaningful relationship was found between the cost data and the design and performance characteristics used in the other equations. It should also be noted that there is a serious discrepancy between the NCIS and NARM cost data for this element. The NARM IMA costs are four to five times greater than those reported in the NCIS. This discrepancy can be explained in part by the fact that the NARM data pick up some labor costs associated with tender ships performing the maintenance function. The NCIS data include only the material used. In any case, the intermediate maintenance cost is relatively small in comparison to other O&S costs associated with its ship.

9. Ship Overhaul

The cost of ship overhaul is estimated somewhat differently from the other cost elements. Instead of directly estimating dollar costs as a function of ship characteristics, the first step in the procedure for this element is to estimate repair man-days per overhaul (RMD). The RMD estimate is then multiplied by the prevailing repair man-day cost rate to generate an estimate of total labor cost per overhaul.[3] A material factor (.25 of labor cost) is then applied to arrive at an estimate of total cost per overhaul. Algebraically the procedure is:

$$\text{Ship Overhaul Cost} = \text{Labor Cost} + \text{Material Cost}$$

where,

$$\text{Labor Cost} = \text{RMD} \times (\text{Cost per RMD})$$

$$\text{Material Cost} = .25 \times (\text{Labor Cost})$$

---

[3]Obtained from Statistics of Naval Shipyards (SONS), Vol. 35-4, 31 December, 1976. The FY76 cost factor is $150.26, which includes labor and overhead and represents an average for all yards.

The sample data were stratified into the following five ship types to permit more refined cost estimation:

Guided Missile Destroyers

Conventional Destroyers

Frigates and Guided Missile Frigates

Cruisers

Carriers

This stratification enables the user of the results to choose the ship type which most closely approximates the one he wishes to estimate. It also requires that the data base be made up of individual observations rather than class averages. The complete data appear in Appendix A. Regression results are discussed below.

9.1. Guided Missile Destroyers

Three explanatory variables, elapsed time since the previous overhaul (INTV), age of the ship when it entered overhaul (AGE), and the ratio of actual ship manning to authorized manning (MAN%), were used to estimate RMD for a Guided Missile Destroyer overhaul. The algebraic signs of the first two variables are expected to be positive, while the third should be negative. The rationale underlying the negative sign is that, as the ship approaches its full complement, more crew maintenance will take place and hence less overhaul effort will be required. The results turned out as expected:

$$\ell n(\text{RMD}) = 7.1227 + \underset{(2.333)}{.36053\ell n(\text{INTV})} + \underset{(3.020)}{.6879\ell n(\text{AGE})} - \underset{(-4.173)}{.01547\ell n(\text{MAN\%})}$$

$\bar{R}^2$ = .745

S.E.E. = .226

DET X'X = .415

F = 69.337

N = 71

where,

RMD = repair man-days per ship overhaul

INTV = elapsed time (in months) since the last overhaul

AGE = age of the ship (in years) at the time it enters overhaul

MAN% = ratio of actual to authorized manning

9.2 Conventional Destroyers

Conventional Destroyer overhaul requirements are estimated with the following equation, where the variables are as defined above:

$$\ell n(\text{RMD}) = \underset{(13.384)}{7.372 + 1.0266\ell n(\text{AGE})}$$

$\bar{R}^2$ = .876

S.E.E. = .195

DET X'X = 1.000

F = 179.139

N = 26

9.3 Frigates and Guided Missile Frigates

The RMD required for overhaul of a Frigate or Guided Missile Frigate is estimated as a function of the same AGE variable employed above, plus two dummy variables defined to capture the technical complexity of installed systems.

The dummies are BOILER, which takes a value of 1 if the ship has pressure-fired boilers and 0 otherwise; and S26/40, which takes a value of 1 if the ship has both the SQS-26 sonar and SPS-40 radar, and 0 otherwise.[4] These two variables, and possibly one or more of the others included in the overhaul equations, may appear to fall in the category of "not useful for CAIG/DSARC purposes." To exclude them, however, when they clearly have a significant bearing on overhaul costs, would give rise to a technical problem known as "specification error." What this means is that the effects of the omitted variables would be spuriously picked up in the included variables' coefficients. This, obviously, would result in misleading cost estimates. Since some of the variables in question represent only the presence or absence of certain characteristics, assigning those values should not prove too difficult. For others - MAN%, for example - sample means can always be used in lieu of anything more specific. This at least assures that the "integrity" of the specification is maintained. Regression results for Frigates and Guided Missile Frigates were:

$$\ell n(\text{RMD}) = 7.8583 + \underset{(2.954)}{.45693}\ell n(\text{AGE}) + \underset{(2.773)}{.41817}(\text{BOILER}) + \underset{(4.574)}{.76585}(\text{S26/40})$$

$$\bar{R}^2 = .667$$

$$\text{S.E.E.} = .240$$

$$\text{DET X'X} = .142$$

$$F = 20.379$$

$$N = 30$$

---

[4] A more complete explanation of these two variables appears on p.3 of the SOCER Study.

9.4 Cruisers

No statistically significant parametric equation could be derived to estimate RMD per Cruiser overhaul. The correlation matrix shown below illustrates the rather weak relationship between RMD and the principal independent variables used in the preceding overhaul equations. It also indicates relatively high intercorrelation between INTV and AGE.

Table 3-2

Cruiser Overhaul Correlation Matrix
N = 28

	RMD	INTV	AGE	MAN%
RMD	1.000			
INTV	.354	1.000		
AGE	.562	.676	1.000	
MAN%	-.161	-.054	-.258	1.000

In light of the above, the sample mean will be used to estimate Cruiser repair man-days. That value is 23,670, with a standard deviation of 11,400.

9.5 Carriers

The RMD requirement per Carrier overhaul is estimated with the following equation, where the variables remain as previously defined:

$$\ell n(\text{RMD}) = 4.32831 + \underset{(5.560)}{1.923}\ell n\ (\text{INTV})$$

$$\bar{R}^2 = .624$$

S.E.E. = .370

DET X'X = 1.000

F = 30.910

N = 19

10. Selected Restricted Availability

The cost of Selected Restricted Availability is estimated by using the corresponding NARM cost factor for this cost element. An average of the Atlantic and Pacific fleets is used.

11. Non-scheduled Ship Repair (RA/TA)

The cost of RA/TA per steaming hour is estimated parametrically. One observation, the DDG-35 class, was dropped from the sample because of curiously large variations in the NCIS data pertaining to this element. The regression results are shown below:

$$\text{RA/TA/SHR} = 28.838 + \underset{(6.752)}{.01471}\ \text{DISP}$$

$$\bar{R}^2 = .774$$

$$\text{S.E.E.} = 229.696$$

$$\text{DET X'X} = 1.000$$

$$F = 45.590$$

$$N = 14$$

where,

RA/TA/SHR = cost of non-scheduled ship repair per steaming hour (underway and not underway) in FY76 dollars

DISP = full load deplacement in tons

12. Fleet Modernization Program

The Fleet Modernization Program is estimated by using the NARM cost factors identified as "FMP INSTALL OMN" and "FMP PROCURE OPN." Averages of the Atlantic and Pacific fleets are used.

13. APA Material Exchanges

The value of this cost element is assumed to be equal to APA Material Issues.

14. APA Material Issues

APA Material Issues are estimated in the manner typically used in the NARM when no direct unit costs are available from a data system. The first step is to obtain the total amount spent for this category for all ships. This information is obtained from Budget Back up for OPN and WPN. The total cost is then allocated to all the ships, utilizing a factor that approximates their relative demand for support. In this case, the factors are based on the OPN portion of the Fleet Modernization Program.

15. - 23. Indirect Operations and Support

The nine Indirect Operations and Support cost elements - Base Operating Support, Training Support, Medical Support, Recruiting & Examining, Transients & Prisoners, Permanent Change of Station, Supply Depot Operations, Second Destination Transportation, and Other Logistic Support - are computed according to the methodology used in the NARM. This procedure estimates costs by applying the FY75 factors to one or more proxy variables. For a comprehensive discussion of this procedure, the reader is referred to the NARM Program Factors Manual, 27 July 1976, pp. 46-58.

4. COST MODEL AND EXAMPLE APPLICATIONS

As mentioned earlier, the cost-estimating relationships described in this report have been incorporated into an automated model which permits rapid computation of O&S cost estimates from a relatively small number of inputs. The model also has a limited capability for the performance of cost sensitivity analysis. As an example of its use, two test applications are included in this section: the Spruance Class Destroyer, DD-963; and the Perry Class Guided Missile Frigate, FFG-7. These ships were selected because complete operating and support data are not yet available on them, and because there is new construction presently underway in each program. The DD-963 class ships are intended as replacements for the large number of World War II destroyers that have undergone extensive modernization (FRAM) to enable them to serve into the 1970's. The Navy plans to construct more than 50 ships of the FFG type for the escort of amphibious forces, underway replenishment groups and mercantile convoys. They are follow-on ships to the large number of FF's built in the 1960's and early 1970's.

The example applications are presented in the form of Tables 4-1 through 4-8. Table 4-2 lists inputs for each ship class. For both the DD-963 and FFG-7 there is a Case 1, Case 2 and Case 3. Case 1 inputs represent "official" program values (as best they can be determined at the present time). Case 2 values are the same as Case 1, except that the authorized crew strength,

both officer and enlisted, has been reduced by 10%. Case 3 values are again the same as Case 1, except for steaming hours underway which has been increased by 20%. These variations from the base Case 1 illustrate the use of the model for sensitivity purposes. The resultant DD cost estimates are shown in Tables 4-3, 4-4 and 4-5, while the FFG figures are given in 4-6, 4-7 and 4-8. All costs are in FY76 dollars. Table 4-1 below presents a summary, at an aggregate level, of the three cases.

TABLE 4-1

Summary of Cases 1, 2 and 3
(FY76 Dollars in Thousands)

	DD-963			FFG-7		
	Total Direct Cost	Total Indir. Cost	Total Annual Cost	Total Direct Cost	Total Indir. Cost	Total Annual Cost
Case 1	2,403	8,097	10,500	1,692	6,714	8,406
Case 2	2,264	7,825	10,089	1,607	6,549	8,156
Case 3	2,470	8,341	10,811	1,738	6,889	8,627

The DD-963 example shows that a decrease of ten percent from base Case 1 in crew size (Case 2) reduces the total annual cost by approximately four percent. Similarly the FFG-7's total annual cost was reduced by about three percent by cutting the crew size ten percent. When the tempo of operations or steaming hours per year was increased from base Case 1 by twenty percent (Case 3), total annual cost for the DD-963 rose three percent. The total annual

cost for the FFG-7 increased by two and one-half percent when the steaming hours per year were increased by twenty percent from the base case.

TABLE 4-2

Model Input Values

Input Parameter List		DD-963	FFG-7
Number of Officers Crew -	Cases 1 & 3	18	12
	Case 2	16	11
Number of Enlisted Crew -	Cases 1 & 3	240	155
	Case 2	216	140
Officer MPN Factor		21,427	21,427
Enlisted MPN Factor		9,248	9,248
Full Load Displacement(tons)		7,800	3,500
Steaming Hours (per year)	Cases 1 & 2	2,639	2,619
	Case 3	3,167	3,143
Age at Median Overhaul (years)		16	16
Interval Between Overhauls (months)		46	37
Duration of Overhaul (months)		3	6
Manning-Percent Authorized		.868	.841
Pressure-Fired Boiler Dummy		***	0
SQS-26 Sonar and SPS-40 Radar Dummy		***	1
Ship Type[1]		8	8
Expendable Stores - Thruput (000)		212	116
Selected Restricted Availability - Thruput		0	0
FMP - Thruput (000)		2,421.0	2,767.0
Exchanges - Thruput (000)		72.7	31.7
Issues - Thruput (000)		72.7	31.7

[1]The indirect O&S cost methodology and IMA cost element operate off of this code. In all, there are eleven ship types: Nuclear Carrier (1), Non-nuclear Carrier (2), Nuclear Sub (3), Non-nuclear Sub (4), CG-16-26, DDG (5), Other Cruisers, Nuclear (6), Other Cruisers, Non-nuclear (7), ASW Ships (8), Underway Replenishment (9), Tenders and Repair Ships (10), and Amphibs (11).

TABLE 4-3

DD-963 COST ESTIMATES: CASE 1

DD-963 ANNUAL SHIP OPERATING AND SUPPORT COSTS ($000)

TOTAL ANNUAL COST			10500.45
DIRECT COSTS		UNIT COSTS($)	ANNUAL COSTS
TOTAL DIRECT			8097.48
UNIT-SHIP OPERATNS			3990.72
MILITARY PERSONNEL		0.	2605.21
OFFICERS	(18)	21427.	385.69
ENLISTED	(240)	9248.	2219.52
TEMP ADDED DUTY		0.	7.50
CONVENTIONAL FUELS		307.	811.45
REPAIR PARTS		49.	128.24
SUPPLIES		0.	108.85
EXPENDABLE STORES		0.	212.00
PURCHASED SERVICES		0.	117.47
UNIT-INTERM. MAINT			53.31
INTERMEDIATE MAINT		0.	53.31
DEPOT MAINTENANCE			3908.09
SHIP OVERHAUL		5146617.	1260.40
SEL. RESTR. AVAIL.		0.	0.00
NON-SCHED SHIP REP		86.	226.69
FLEET MOD PROGRAM		0.	2421.00
RECURRING INVSTMNT			145.37
EXCHANGES		0.	72.68
ISSUES		0.	72.68

INDIRECT COSTS	OFF	ENL	MPN	O&M	ANNUAL COSTS
TOTAL INDIRECT					2402.97
BASE OPERATNS SUPT	.55	6.98	76.36	119.63	196.00
TRAINING SUPPORT	2.32	31.77	343.58	59.08	402.66
MEDICAL SUPPORT	2.52	6.02	109.70	91.80	201.50
RECRUIT & EXAMINE	.23	1.97	23.23	25.30	48.52
TRANSNTS & PRISNRS	1.07	13.24	145.43	0.00	145.43
PERM CHANGE OF STA			166.40		166.40
SUPPLY DEPOT OPERS					98.57
2ND DESTINATN TRAN					163.24
OTHR LOGISTIC SUPT					980.64

TABLE 4-4

DD-963 COST ESTIMATES: CASE 2

DD-963 ANNUAL SHIP OPERATING AND SUPPORT COSTS ($000)

TOTAL ANNUAL COST ----------			10089.75
DIRECT COSTS		UNIT COSTS($)	ANNUAL COSTS
TOTAL DIRECT			7825.28
UNIT-SHIP OPERATNS			3718.52
MILITARY PERSONNEL		0.	2340.40
OFFICERS	(16)	21427.	342.83
ENLISTED	(216)	9248.	1997.57
TEMP ADDED DUTY		0.	6.55
CONVENTIONAL FUELS		307.	811.45
REPAIR PARTS		49.	128.24
SUPPLIES		0.	102.39
EXPENDABLE STORES		0.	212.00
PURCHASED SERVICES		0.	117.47
UNIT-INTERM. MAINT			53.31
INTERMEDIATE MAINT		0.	53.31
DEPOT MAINTENANCE			3908.09
SHIP OVERHAUL		5146617.	1260.40
SEL. RESTR. AVAIL.		0.	0.00
NON-SCHED SHIP REP		86.	226.69
FLEET MOD PROGRAM		0.	2421.00
RECURRING INVSTMNT			145.37
EXCHANGES		0.	72.68
ISSUES		0.	72.68

INDIRECT COSTS	OFF	ENL	MPN	O&M	ANNUAL COSTS
TOTAL INDIRECT					2264.47
BASE OPERATNS SUPT	.50	6.28	68.67	107.58	176.24
TRAINING SUPPORT	2.07	28.59	308.86	53.13	361.99
MEDICAL SUPPORT	2.27	5.42	98.65	82.55	181.20
RECRUIT & EXAMINE	.21	1.77	20.90	22.77	43.67
TRANSNTS & PRISNRS	.95	11.92	130.64	0.00	130.64
PERM CHANGE OF STA			149.41		149.41
SUPPLY DEPOT OPERS					91.88
2ND DESTINATN TRAN					162.87
OTHR LOGISTIC SUPT					966.57

TABLE 4-5

DD-963 COST ESTIMATES: CASE 3

DD-963 ANNUAL SHIP OPERATING AND SUPPORT COSTS ($000)

TOTAL ANNUAL COST ----------					10811.62
DIRECT COSTS			UNIT COSTS($)		ANNUAL COSTS
TOTAL DIRECT					8341.51
UNIT-SHIP OPERATNS					4178.73
MILITARY PERSONNEL			0.		2605.21
OFFICERS	(18)		21427.		385.69
ENLISTED	(240)		9248.		2219.52
TEMP ADDED DUTY			0.		7.50
CONVENTIONAL FUELS			307.		973.81
REPAIR PARTS			49.		153.90
SUPPLIES			0.		108.85
EXPENDABLE STORES			0.		212.00
PURCHASED SERVICES			0.		117.47
UNIT-INTERM. MAINT					63.97
INTERMEDIATE MAINT			0.		63.97
DEPOT MAINTENANCE					3953.44
SHIP OVERHAUL			5146617.		1260.40
SEL. RESTR. AVAIL.			0.		0.00
NON-SCHED SHIP REP			86.		272.05
FLEET MOD PROGRAM			0.		2421.00
RECURRING INVSTMNT					145.37
EXCHANGES			0.		72.68
ISSUES			0.		72.68

INDIRECT COSTS	OFF	ENL	MPN	O&M	ANNUAL COSTS
TOTAL INDIRECT					2470.10
BASE OPERATNS SUPT	.55	6.98	76.36	119.63	196.00
TRAINING SUPPORT	2.32	31.77	343.58	59.08	402.66
MEDICAL SUPPORT	2.52	6.02	109.70	91.80	201.50
RECRUIT & EXAMINE	.23	1.97	23.23	25.30	48.52
TRANSNTS & PRISNRS	1.07	13.24	145.43	0.00	145.43
PERM CHANGE OF STA			166.40		166.40
SUPPLY DEPOT OPERS					104.33
2ND DESTINATN TRAN					177.21
OTHR LOGISTIC SUPT					1028.05

TABLE 4-6

FFG-7 COST ESTIMATES: CASE 1

FFG-7 ANNUAL SHIP OPERATING AND SUPPORT COSTS ($000)

TOTAL ANNUAL COST ----------			8627.42
DIRECT COSTS		UNIT COSTS($)	ANNUAL COSTS
TOTAL DIRECT			6888.55
UNIT-SHIP OPERATNS			2908.31
MILITARY PERSONNEL		0.	1680.56
OFFICERS	(12)	21427.	257.12
ENLISTED	(155)	9248.	1433.44
TEMP ADDED DUTY		0.	4.20
CONVENTIONAL FUELS		259.	814.66
REPAIR PARTS		37.	117.19
SUPPLIES		0.	86.26
EXPENDABLE STORES		0.	116.00
PURCHASED SERVICES		0.	79.44
UNIT-INTERM. MAINT			43.37
INTERMEDIATE MAINT		0.	43.37
DEPOT MAINTENANCE			3873.53
SHIP OVERHAUL		3709990.	1035.35
SEL. RESTR. AVAIL.		0.	0.00
NON-SCHED SHIP REP		23.	71.18
FLEET MOD PROGRAM		0.	2767.00
RECURRING INVSTMNT			63.33
EXCHANGES		0.	31.67
ISSUES		0.	31.67

INDIRECT COSTS	OFF	ENL	MPN	O&M	ANNUAL COSTS
TOTAL INDIRECT					1738.87
BASE OPERATNS SUPT	.36	4.52	49.43	77.44	126.87
TRAINING SUPPORT	1.53	20.53	222.57	38.24	260.80
MEDICAL SUPPORT	1.63	3.90	71.00	59.42	130.42
RECRUIT & EXAMINE	.15	1.27	15.00	16.34	31.34
TRANSNTS & PRISNRS	.71	8.55	94.39	0.00	94.39
PERM CHANGE OF STA			108.13		108.13
SUPPLY DEPOT OPERS					70.50
2ND DESTINATN TRAN					132.28
OTHR LOGISTIC SUPT					784.14

TABLE 4-7

FFG-7 COST ESTIMATES: CASE 2

FFG-7 ANNUAL SHIP OPERATING AND SUPPORT COSTS ($000)

TOTAL ANNUAL COST ----------				8157.00
DIRECT COSTS			UNIT COSTS($)	ANNUAL COSTS
TOTAL DIRECT				6549.39
UNIT-SHIP OPERATNS				2588.26
MILITARY PERSONNEL			0.	1530.42
OFFICERS	(11)		21427.	235.70
ENLISTED	(140)		9248.	1294.72
TEMP ADDED DUTY			0.	3.62
CONVENTIONAL FUELS			259.	678.84
REPAIR PARTS			37.	97.65
SUPPLIES			0.	82.28
EXPENDABLE STORES			0.	116.00
PURCHASED SERVICES			0.	79.44
UNIT-INTERM. MAINT				36.14
INTERMEDIATE MAINT			0.	36.14
DEPOT MAINTENANCE				3861.66
SHIP OVERHAUL			3709990.	1035.35
SEL. RESTR. AVAIL.			0.	0.00
NON-SCHED SHIP REP			23.	59.31
FLEET MOD PROGRAM			0.	2767.00
RECURRING INVSTMNT				63.33
EXCHANGES			0.	31.67
ISSUES			0.	31.67

INDIRECT COSTS	OFF	ENL	MPN	O&M	ANNUAL COSTS
TOTAL INDIRECT					1607.61
BASE OPERATNS SUPT	.32	4.09	44.69	70.02	114.71
TRAINING SUPPORT	1.39	18.55	201.32	34.57	235.89
MEDICAL SUPPORT	1.48	3.52	64.19	53.73	117.92
RECRUIT & EXAMINE	.14	1.15	13.55	14.76	28.31
TRANSNTS & PRISNRS	.65	7.73	85.46	0.00	85.46
PERM CHANGE OF STA			97.96		97.96
SUPPLY DEPOT OPERS					62.33
2ND DESTINATN TRAN					122.06
OTHR LOGISTIC SUPT					742.97

TABLE 4-8

FFG-7 COST ESTIMATES: CASE 3

FFG-7 ANNUAL SHIP OPERATING AND SUPPORT COSTS ($000)

TOTAL ANNUAL COST ----------			8406.28
DIRECT COSTS		UNIT COSTS($)	ANNUAL COSTS
TOTAL DIRECT			6714.09
UNIT-SHIP OPERATNS			2752.96
MILITARY PERSONNEL		0.	1690.56
OFFICERS	(12)	21427.	257.12
ENLISTED	(155)	9248.	1433.44
TEMP ADDED DUTY		0.	4.20
CONVENTIONAL FUELS		259.	678.84
REPAIR PARTS		37.	97.65
SUPPLIES		0.	86.26
EXPENDABLE STORES		0.	116.00
PURCHASED SERVICES		0.	79.44
UNIT-INTERM. MAINT			36.14
INTERMEDIATE MAINT		0.	36.14
DEPOT MAINTENANCE			3861.66
SHIP OVERHAUL		3709990.	1035.35
SEL. RESTR. AVAIL.		0.	0.00
NON-SCHED SHIP REP		23.	59.31
FLEET MOD PROGRAM		0.	2767.00
RECURRING INVSTMNT			63.33
EXCHANGES		0.	31.67
ISSUES		0.	31.67

INDIRECT COSTS	OFF	ENL	MPN	O&M	ANNUAL COSTS
TOTAL INDIRECT					1692.18
BASE OPERATNS SUPT	.36	4.52	49.43	77.44	126.87
TRAINING SUPPORT	1.53	20.53	222.57	38.24	260.80
MEDICAL SUPPORT	1.63	3.90	71.00	59.42	130.42
RECRUIT & EXAMINE	.15	1.27	15.00	16.34	31.34
TRANSNTS & PRISNRS	.71	8.55	94.39	0.00	94.39
PERM CHANGE OF STA			108.13		108.13
SUPPLY DEPOT OPERS					66.38
2ND DESTINATN TRAN					122.29
OTHR LOGISTIC SUPT					751.56

5. MODEL ASSESSMENT

The discussion in this section will detail the five major categories of operating and support costs estimated by the model and reported in Section 4. Additional relevant material is contained in Appendix B, which presents a comparison of NCIS and NARM costs by ship class.

Ship Operations

This category accounts for roughly one-half of total direct costs and some thirty-five to forty percent of total annual costs.[1] Personnel and fuel costs together represent about eighty-five percent of the category.

Intermediate Maintenance

No significant statistical relationships between intermediate maintenance cost and several explanatory variables could be established; therefore, the IMA costs were estimated by factors developed from the NCIS data. There is a considerable discrepancy in the NARM and corresponding NCIS data for this category (reference Appendix B, Table 1), which suggests further work in this area seems advisable. Given all of this, however, the IMA costs amount to only one percent of the total direct costs.

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[1]The percentages referred to in this discussion are taken from the DD-963 and FFG-7 estimates presented in Section 4. They are approximations at best and are intended only to put the different cost categories in some rough quantitative perspective.

Depot Maintenance

Here lies the potential for substantial refinement. These costs are about as large as Ship Operations; i.e., approximately 50 percent of total direct costs and 40 percent of total annual costs. The two elements of concern are Ship Overhaul and the Fleet Modernization Program (FMP). Although this study benefitted considerably from access to the SOCER data base on overhaul costs, that data is not nearly as current as one would like (covering the period FY62-72), and the regression results were not always satisfactory. Further work in this area seems advisable.

The FMP is another very large cost element (estimated here as 30 percent to 40 percent of total direct costs) which rests on a less-than-adequate empirical and analytic base. The estimates presented here are based on NARM factors, but a question arises as to the reasonableness of assigning such large annual "modernization" costs to classes of ships which are still in new construction. Again, further work would be fruitful, although experience indicates this is a very difficult area for analysis.[2]

Recurring Investment

As discussed earlier in the report, obtaining data on APA Material Exchanges and Issues poses formidable problems. Continued allocation of budget line-item totals may be the only feasible approach for the near future, although the VAMOSC Study has suggested the possibility of obtaining actual ex-

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[2]Administrative Sciences Corporation conducted an FMP cost study in 1973. The data were found to be quite erratic from year to year, and to also reveal changes in the relative importance of different ship types over time. See "A Statistical Description and Analysis of the Fleet Modernization Program" (U), ASC R-105, August 1973, CONFIDENTIAL.

penditure data from ship departure reports. Fortunately, this category appears to represent at most 2 percent of total direct costs, and is therefore of only minor importance.

Indirect Operations and Support

The NARM indirect O&S cost methodology has been recognized for some time throughout the Navy and in OSD as a very creditable approach toward dealing with this conceptually and empirically difficult area of cost analysis.

APPENDIX A

DATA BASE FOR COST-ESTIMATING RELATIONSHIPS

TABLE A-1

DATA BASE FOR TEMPORARY ADDITIONAL
DUTY COST-ESTIMATING RELATIONSHIP

Ship	TAD Cost	Crew Size
FF-1037	3500	208
FF-1040	10400	260
FF-1052	6760	251
DDG-2	11304	339
DDG-35	15500	346
DDG-37	13333	394
DD-FRAM/I	6000	290
DD-931	9778	311
DD-945	9600	306
CG-16	11555	401
CG-26	17777	444
FFG-1	9833	261
CVA/CV	113000	2888
CGN-36	7000	543
CVAN-65	100000	3061

TAD Cost Source: Navy Cost Information System (NCIS)

Crew Size Source: Navy Program Factors Manual (NARM), July 1976

TABLE A-2

DATA BASE FOR CONVENTIONAL FUEL
COST-ESTIMATING RELATIONSHIP

Ship	POL/SHR	Full Load Displacement (Tons)	Nuclear Dummy	Shaft Horsepower
FF-1037	130.7	2650	0	20000
FF-1040	369.4	3400	0	35000
FF-1052	202.6	4100	0	35000
DDG-2	234.7	4500	0	70000
DDG-35	284.8	5200	0	80000
DDG-37	424.7	5800	0	85000
DD-FRAM/I	203.9	3500	0	60000
DD-931	237.3	4050	0	70000
DD-945	227.9	4050	0	70000
CG-16	392.5	7800	0	85000
CG-26	312.8	7930	0	85000
FFG-1	230.0	3245	0	35000
CVA/CV	900.7	80800	0	280000
CGN-36	8.8	10150	1	70000
CVAN-65	33.7	89650	1	280000

POL/SHR Cost Source: Navy Cost Information System (NCIS)

Full Load Displacement Source: Jane's Fighting Ships, 1975-76

Shaft Horsepower Source: Jane's Fighting Ships, 1975-76

TABLE A-3

DATA BASE FOR REPAIR PARTS
COST-ESTIMATING RELATIONSHIP

Ship	Repair Parts/SHP	Full Load Displacement (Tons)
FF-1037	18	2650
FF-1040	37	3400
FF-1052	40	4100
DDG-2	55	4500
DDG-35	57	5200
DDG-37	50	5800
DD-FRAM/I	15	3500
DD-931	32	4050
DD-945	44	4050
CG-16	50	7800
CG-26	50	7930
FFG-1	36	3245
CVA/CV	173	80800
CGN-36	64	10150
CVAN-65	323	89650

Repair Parts/SHP Cost Source: Navy Cost Information System (NCIS)

Full Load Displacement Source: Jane's Fighting Ships, 1975-76

TABLE A-4

DATA BASE FOR SUPPLIES
COST-ESTIMATING RELATIONSHIP

Ship	Supplies Cost	Crew Size	Nuclear Dummy
FF-1037	162500	208	0
FF-1040	157300	260	0
FF-1052	132804	251	0
DDG-2	198695	339	0
DDG-35	145500	346	0
DDG-37	259888	394	0
DD-FRAM/I	83941	290	0
DD-931	193111	311	0
DD-945	138400	306	0
CG-16	191777	401	0
CG-26	171777	444	0
FFG-1	133000	261	0
CVA/CV	276800	2888	0
CGN-36	165000	543	1
CVAN-65	1777000	3061	1

Supplies Cost Source: Navy Cost Information System (NCIS)

Crew Size Source: Navy Program Factors Manual (NARM), July 1976

TABLE A-5

DATA BASE FOR PURCHASED SERVICES
COST-ESTIMATING RELATIONSHIP

Ship	Purchased Services Cost	Full Load Displacement (Tons)
FF-1037	99500	2650
FF-1040	67500	3400
FF-1052	91869	4100
DDG-2	93043	4500
DDG-35	97000	5200
DDG-37	87444	5800
DD-FRAM/I	78529	3500
DD-931	82333	4050
DD-945	87600	4050
CG-16	125111	7800
CG-26	102111	7930
FFG-1	93000	3245
CVA/CV	450000	80800
CGN-36	144000	10150
CVAN-65	1123000	89650

Purchased Services Cost Source: Navy Cost Information System (NCIS)

Full Load Displacement Source: Jane's Fighting Ships, 1975-76

TABLE A-6

DATA BASE FOR NON-SCHEDULED
SHIP REPAIR COST-ESTIMATING RELATIONSHIP

Ship	RA/TA/SHR Cost	Full Load Displacement (Tons)
FF-1037	81.2	2650
FF-1040	87.8	3400
FF-1052	100.6	4100
DDG-2	82.1	4500
DDG-35	1249.5	5200
DDG-37	171.1	5800
DD-FRAM/I	124.8	3500
DD-931	52.0	4050
DD-945	212.2	4050
CG-16	105.8	7800
CG-26	84.6	7930
FFG-1	162.3	3245
CVA/CV	661.6	80800
CGN-36	23.7	10150
CVAN-65	1862.8	89650

RA/TA/SHR Cost Source: Navy Cost Information Systems (NCIS)

Full Load Displacement Source: Jane's Fighting Ships, 1975-76

TABLE A-7

DATA BASE FOR GUIDED MISSILE DESTROYER
OVERHAUL COST-ESTIMATING RELATIONSHIP

Ship	Repair Man-days	Interval Between Ovh. (Months)	Age At Ovh. (Years)	Percent Manned
DDG-2	8817	24.5	2.62	.906
DDG-2	24474	35.2	5.88	.883
DDG-2	34818	45.5	10.22	.863
DDG-3	7727	26.2	2.75	.900
DDG-3	20641	40.1	6.38	.838
DDG-3	27847	35.3	9.93	.890
DDG-4	15726	26.3	2.90	.694
DDG-4	23577	38.2	6.50	.880
DDG-4	39638	31.9	9.68	.881
DDG-5	28249	43.8	7.84	.870
DDG-5	18091	34.2	3.58	.844
DDG-6	27778	38.2	7.33	.873
DDG-7	6420	19.0	2.36	.887
DDG-7	22693	48.7	9.60	.870
DDG-8	6750	18.6	2.60	.933
DDG-8	12303	30.1	5.37	.893
DDG-8	19412	29.9	8.26	.820
DDG-9	11071	27.5	2.95	.852
DDG-9	12527	30.8	5.85	.913
DDG-10	9497	26.0	2.79	.851
DDG-10	13481	39.3	6.37	.862
DDG-10	26065	43.1	10.55	.879
DDG-11	11303	31.3	3.33	.887
DDG-11	27627	56.0	8.48	.872
DDG-12	7641	17.6	2.13	.924
DDG-12	12959	27.8	4.77	.866
DDG-12	16396	32.1	7.83	.850
DDG-13	11547	25.2	3.33	.886
DDG-13	13503	31.1	6.25	.890
DDG-13	29200	28.1	9.07	.815
DDG-14	13324	18.0	2.25	.682
DDG-14	10435	30.1	5.11	.913
DDG-15	7293	17.9	2.29	.760
DDG-15	15151	44.3	6.32	.901
DDG-16	11732	41.9	4.34	.891
DDG-16	23621	33.3	7.61	.864
DDG-17	19496	35.1	3.58	.819
DDG-17	29169	38.3	7.34	.893
DDG-18	19963	36.4	3.73	.698
DDG-18	29096	39.9	7.64	.917

Repair Man-days Source: SOCER Study
Interval Between Ovh. Source: Same as above
Age At Ovh. Source: Same as above
Percent Manned Source: Same as above

TABLE A-7 (cont'd.)

Ship	Repair Man-days	Interval Between Ovh. (Months)	Age At Ovh. (Years)	Percent Manned
DDG-19	14510	30.4	3.35	.897
DDG-19	32541	42.8	7.46	.862
DDG-20	12044	24.2	2.75	.749
DDG-20	16166	29.9	5.83	.829
DDG-21	9865	26.8	2.65	.889
DDG-21	16687	30.2	5.75	.890
DDG-22	11782	31.7	3.50	.887
DDG-22	21209	31.8	6.71	.813
DDG-23	13418	35.5	3.69	.890
DDG-23	28932	33.9	7.05	.917
DDG-24	8939	27.0	2.93	.945
DDG-24	19178	35.6	6.43	.868
DDG-37	16777	35.5	3.62	.914
DDG-38	12492	31.7	3.37	.912
DDG-38	24336	30.1	6.26	.845
DDG-39	14073	29.5	3.23	.741
DDG-39	30954	57.6	8.55	.943
DDG-40	12582	30.9	3.23	.921
DDG-40	14450	29.5	6.20	.881
DDG-41	24372	60.8	8.94	.965
DDG-42	11666	36.4	3.69	.974
DDG-42	15151	36.4	7.18	.954
DDG-42	25623	32.2	10.36	.968
DDG-43	12379	23.1	2.78	.910
DDG-43	14166	42.8	6.75	.859
DDG-44	17481	27.0	3.06	.704
DDG-44	20905	35.1	6.36	.900
DDG-45	8663	30.0	3.16	.909
DDG-45	29241	38.0	6.58	.916
DDG-46	7788	18.0	2.16	.920
DDG-46	12091	39.6	5.74	.886

TABLE A-8

DATA BASE FOR CONVENTIONAL DESTROYER
OVERHAUL COST-ESTIMATING RELATIONSHIP

Ship	Repair Man-days	Age at Ovh. (Years)
DD-931	10577	7.76
DD-931	23044	12.23
DD-931	29084	16.07
DD-933	28124	15.45
DD-937	11945	7.07
DD-938	10006	6.15
DD-940	22085	9.08
DD-941	12216	7.00
DD-942	8762	5.17
DD-942	11055	8.54
DD-942	20083	12.31
DD-943	10613	6.66
DD-944	9011	5.18
DD-944	21847	10.00
DD-945	10163	7.55
DD-945	32324	11.81
DD-946	6107	4.04
DD-946	12495	7.68
DD-946	13651	10.66
DD-947	4779	2.66
DD-948	9627	6.12
DD-949	4191	2.01
DD-950	4890	3.06
DD-950	7529	6.41
DD-951	9065	5.37
DD-951	13839	9.32

Repair Man-days Source: SOCER Study

Age at Ovh. Source: Same as above

TABLE A-9

DATA BASE FOR FRIGATES AND GUIDED MISSILE
FRIGATES OVERHAUL COST-ESTIMATING RELATIONSHIPS

Ship	Repair Man-days	Age at Ovh. (Years)	Boiler Dummy	SQS 26/ SPS 40 Dummy
FFG-1	16010	4.43	1	1
FFG-2	14067	3.11	1	1
FFG-3	15836	3.35	1	1
FFG-4	12808	2.46	1	1
FFG-5	14951	3.51	1	1
FFG-6	32347	3.17	1	1
FF-1033	7927	7.83	0	0
FF-1033	8180	11.25	0	0
FF-1034	6445	7.91	0	0
FF-1034	8730	11.42	0	0
FF-1035	6486	7.95	0	0
FF-1035	7803	11.42	0	0
FF-1036	5187	7.91	0	0
FF-1036	7823	11.50	0	0
FF-1037	9834	4.64	0	1
FF-1037	18620	8.35	0	1
FF-1038	9602	3.69	0	1
FF-1038	13058	7.30	0	1
FF-1040	11954	3.18	1	1
FF-1040	19896	7.12	1	1
FF-1041	12170	3.41	1	1
FF-1041	20692	6.51	1	1
FF-1043	12768	2.96	1	1
FF-1044	19548	5.92	1	1
FF-1045	11185	3.48	1	1
FF-1047	13079	3.68	1	1
FF-1048	12026	2.96	1	1
FF-1049	9149	3.31	1	1
FF-1050	16113	2.05	1	1
FF-1051	21144	3.53	1	1

Repair Man-days Source: SOCER Study
Age at Ovh. Source: Same as above
Boiler Dummy: Same as above
SQS26/SPS40 Dummy: Same as above

TABLE A-10

DATA BASE FOR CARRIER OVERHAUL
COST-ESTIMATING RELATIONSHIP

Ship	Repair Man-Days	Interval Between Ovh. (Months)
CVA-59	51163	29.8
CVA-59	131932	51.2
CVA-59	175198	53.8
CVA-60	47826	39.5
CVA-61	43546	38.1
CVA-61	52854	29.7
CVA-62	50795	44.2
CVA-62	145434	44.7
CVA-63	85671	28.7
CVA-63	164958	52.4
CVA-64	82985	32.7
CVA-64	219552	54.3
CVA-66	110813	41.1
CVA-41	38242	27.2
CVA-42	62180	30.4
CVA-42	187691	54.6
CVA-43	37259	29.0
CVA-43	99824	35.1
CVA-43	184166	50.0

Repair Man-Days Source: SOCER Study

Interval Between Ovh. Source: Same as above

APPENDIX B

COMPARISON OF NARM AND NCIS DATA

TABLE B-1

COMPARISON OF NARM AND NCIS
(FY76 Dollars in Thousands)

	Conventional Fuel		Purchased Services		Supplies		Repair Parts	
	NARM	NCIS	NARM	NCIS	NARM	NCIS	NARM	NCIS
FF-1037	706.5	439.0	87.0	99.5	98.0	162.5	227.5	60.4
FF-1040	708.0	1,176.8	87.0	67.5	98.0	157.3	227.5	116.6
FF-1052	925.5	733.4	87.0	91.9	98.0	132.8	227.5	143.7
DDG-2	1,017.0	757.5	121.0	93.0	199.0	198.7	347.5	176.3
DDG-35	889.0	799.8	121.0	97.0	199.0	145.5	347.5	161.2
DDG-37	1,897.5	1,792.2	121.0	87.4	199.0	259.9	347.5	211.4
DD-FRAM I	1,039.5	838.9	118.0	78.5	123.5	83.9	195.0	63.5
DD-931	1,155.0	711.4	150.0	82.3	156.0	193.1	256.0	96.7
DD-945	745.0	518.8	122.0	87.6	152.0	138.4	256.0	99.9
CG-16	1,961.5	1,620.0	204.0	125.1	262.0	191.8	464.5	207.4
CG-26	1,910.0	1,331.7	204.0	102.0	262.0	171.8	464.5	214.7
FFG-1	817.0	602.6	84.0	93.0	148.5	133.0	179.0	95.2
CVA/CV	7,384.0	4,236.3	328.0	450.0	1,781.0	276.8	1,987.0	813.8
CGN-36	17.0	28.3	360.0	144.0	358.5	165.0	650.0	217.1
CVAN	143.0	137.0	150.0	1,123.0	2,520.0	1,777.0	3,469.0	1,352.0

TABLE B-1 (Cont'd.)

COMPARISON OF NARM AND NCIS
(FY76 Dollars in Thousands)

	Fleet TAD		Intermediate Maintenance		RA/TA	
	NARM	NCIS	NARM	NCIS	NARM	NCIS
FF-1037	6.0	3.5	217.0	28.6	302.5	272.6
FF-1040	7.0	10.4	217.0	50.1	359.0	258.6
FF-1052	7.0	6.8	226.0	45.6	359.0	364.1
DDG-2	11.0	11.3	292.5	60.8	353.0	264.8
DDG-35	11.0	15.5	292.5	67.1	353.0	3,509.3
DDG-37	13.0	13.3	201.5	74.2	353.0	722.0
DD-FRAM I	32.0	6.0	289.5	60.9	572.5	513.2
DD-931	35.0	9.8	267.0	69.6	774.0	155.9
DD-945	35.0	9.6	320.0	38.8	530.0	483.0
CG-16	11.0	11.6	201.5	42.5	511.0	436.7
CG-26	12.0	17.8	201.5	42.5	511.0	360.7
FFG-1	50.0	9.8	131.5	36.2	303.0	3,273.9
CVA/CV	110.0	113.0	116.0	3.4	1,931.0	3,111.6
CGN-36	15.0	7.0	51.5	6.6	850.5	81.0
CVAN	116.0	100.0	51.0	13.0	825.0	7,576.0

PART II

SUMMARY OF RESEARCH PROJECT

PART II: SUMMARY OF RESEARCH PROJECT

On September 1, 1972, Administrative Sciences Corporation entered into a contract with the Office of Naval Research to provide cost analysis and other analytical support to the Chief of Naval Operations, Advisor for Resource Analysis (Op-96D). The contract ended on July 31, 1977. What follows is a summary of the major products of that effort.

Annual/Technical Reports

1. "A Statistical Description and Analysis of the Fleet Modernization Program, (U)," ASC R-105, Annual Report: Volume I, August 31, 1973 (CONFIDENTIAL). This study, which produced a comprehensive Fleet Modernization Program (FMP) data base, focused on: (a) the difference between budgeted and actual FMP expenditures; (b) the influence of ship age on the costs of alterations; (c) the substantial increase in the FMP budget for FY74; and (d) the relationship between FMP costs, force structure variables, and ship design and performance characteristics. FMP cost-estimating factors were developed and used to distribute annual OPN costs (aviation portions excluded) to major ship types.

2. "Ridge Regression with Non-Zero Priors: Some Monte Carlo Results," ASC R-105, Annual Report: Volume II, August 31, 1973. This report discusses the use of Ridge Analysis, or Ridge Regression, in defense systems costing. It presents a rationale and method for introducing explicit non-zero prior estimates for each of the unknown regression parameters. (Standard Ridge procedures implicitly use zero priors.) A Monte Carlo exercise was conducted, the outcome indicating that defense cost analysts' needs with respect to

parameter estimation and prediction can be served quite well by Ridge methods in cases where "good" or even "fair" prior information is available.

3. "A Parametric Model for Estimating Naval Aircraft Operating and Support Costs (U)," ASC R-107, Annual Report, August 31, 1974 (CONFIDENTIAL). This report begins by identifying and defining a set of Naval aircraft operating and support cost categories. It discusses the extent to which corresponding historical data are available by type/model/series aircraft, and then describes a computer-programmed statistical cost model which estimates each of the costs for any given fixed-wing Naval aircraft. The estimates are based principally on the aircraft's design, performance and maintenance parameters.

4. "Force Mix and Related Aircraft System Cost Analysis (U)," ASC R-109, Annual Report, August 31, 1975 (CONFIDENTIAL). This study describes the cost analysis performed in connection with the NAVAL ESCORT FORCE MIX STUDY, as well as the revision and updating of the aircraft operating and support parametric cost model reported in ASC R-107.

5. "Draft Navy Operating and Support Cost Guide for Aircraft Systems," 30 January 1976. This was a full text draft of an O&S cost guide for Naval aircraft. It was prepared as a response to the Operating and Support Cost Development Guide for Aircraft Systems, published by the CAIG in May 1974. It was designed to adapt the CAIG guidance to the Navy environment. Specifically, changes were made to accommodate Navy organizational structures, accounting procedures, and support systems.

6. "Naval Ship Operating and Support Costs: A Preliminary Estimating Capability," Technical Memorandum, October 7, 1976. This report provides an initial capability for the estimation of operating and support costs for

Naval ships. Its primary data sources were the Navy Cost Information System and the Center for Naval Analyses' Ship Overhaul Cost Estimating Relationships (SOCER) study. Cost-estimating factors and/or relationships are presented for aircraft carriers, surface combatants and nuclear attack submarines.

Navy Publications With Contributions Provided by ASC

1. "Visibility and Management of Support Costs," Draft Report, December 1974.

2. "Visibility and Management of Support Costs," Final Report, April 14, 1975.

4. "Independent Cost Estimate of VCX for the Cost Analysis Improvement Group," Resource Analysis Group, Systems Analysis Division, Department of the Navy, September 1975.

4. "Av-8B Independent Cost Estimate for DSARC I," Resource Analysis Group, Systems Analysis Division, Department of the Navy, March 1976.

5. "LAMPS MKIII for DSARC IIB," Resource Analysis Group, Systems Analysis Division, Department of the Navy, March 1976.

6. "F-18 Independent Cost Estimate for Cost Analysis Improvement Group," Resource Analysis Group, Systems Analysis Division, Department of the Navy, November 1975.

7. "CH-53E Independent Cost Estimate for Cost Analysis Improvement Group," Resource Analysis Group, Systems Analysis Division, Department of the Navy, March 1975.

8. TASES Independent Cost Estimate, Resource Analysis Group, System Analysis Division, Department of the Navy, May 1976.

MEMORANDA

1. "Mike Klein's Paper on Uncertainty," Memorandum to Joe Kammerer, January 22, 1973.

2. "Proposed Costing Guidelines for FORCE MIX Study," Memorandum to Op-96D, August 14, 1974.

3. "Billet Costs," Memorandum to Op-96D, December 11, 1974.

4. "Billet Costs and FORCE MIX Study," Memorandum to Op-96D, January 7, 1975.

5. "Aircraft Maintenance Labor Rates," Memorandum to Cmdr. Walsh, June 5, 1975.

6. "The Navy Program Factors Manual," Memorandum to Joseph T. Kammerer, July 30, 1975.

7. "Cost Elements for CAIG/DSARC Reviews," Memorandum to Cmdr. Walsh, August 4, 1975.

8. "Data System Requirements for Reporting Operating and Support (O&S) Costs," Memorandum to Joseph T. Kammerer, September 8, 1975.

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The report is in two parts. Part I details the development and implementation of an operating and support cost model for aircraft carriers and surface combatants. Twenty-three O&S cost elements were identified and defined, with close adherence being maintained to the draft CAIG Operating and Support Cost Development Guide for Naval Ships, the Navy Resource Model (NARM), and the work of the Visibility and Management of Support Costs (VAMOSC) Study Group. Cost data were obtained from three principal sources: Navy Cost Information

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System (NCIS), NARM Program Factors, and the Center for Naval Analyses' SOCER Study. Procedures consisting of parametric cost-estimating relationships, cost factors and "thruput" estimates were developed for the full set of cost elements. Those procedures were incorporated into an automated model which was then used to estimate annual O&S costs for the DD-963 and the FFG-7.

Part II of the report summarizes all the work accomplished under the contract and provides a listing of all technical reports submitted.